भारतीय प्रौद्योगिकी संस्थान खड़गपुर
खड़गपुर-७२१ ३०२
Indian Institute of Technology Kharagpur
Kharagpur – 721302

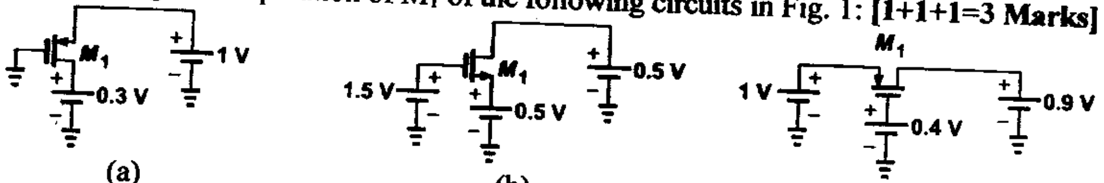
Mid-Semester Exam

Date: ________ **FN/AN** **Time:** 2 hours; **Full Marks:** 90 **Number of Students:** 260
Spring Semester - 2017-2018 **Department:** E & ECE **II year B. Tech.**
Subject no. EC 21008 **Subject name:** Analog Electronic Circuits

Instruction:

1. Answers of all parts of a question must be at one place.
2. Wherever it is necessary, you may use assumption(s) with reasonable justification
3. Assume BJTs are in active mode and MOSFETs are in saturation for the circuits where numerical values of bias voltage and currents are not given.
4. For BJTs Unless otherwise stated use, $|V_{BE(on)}| \approx 0.6V$, $|V_{CE(sat)}| = 0.3V$, $V_A = 100V$, and $V_T = 25mV$.
5. For NMOS and PMOS, unless otherwise stated, assume μ_nC_{ox} = 200 $\mu A/V^2$, μ_pC_{ox} = 100 $\mu A/V^2$, and V_{TH} = 0.4 V for NMOS devices and -0.4 V for PMOS devices.

1. Determine the region of operation of M_1 of the following circuits in Fig. 1: **[1+1+1=3 Marks]**



(a) (b) (c)

Fig. 1

2. Answer the following multiple-choice questions: **[1 + 3 + 1 = 5 Marks]**

(a) The small-signal resistance (i.e., dV_B/dI_D) in kΩ offered by the n-channel MOSFET, M, shown in Fig. 2, at a bias point of V_B=2 V is (device data for M: $\mu_nC_{ox}(W/L) = 80\,\mu AV^2$, threshold voltage V_{TN} = 1 V, and neglect channel length modulation),

i. 6.25 ii. 25 iii. 12.5 iv. 100

Fig. 2

(b) Consider the circuit in Fig. 3, where v_1 represents the signal generated by a microphone, $I_S = 6 \times 10^{-16} A, \beta = 100$, and $V_A = 50\ V$. Obtain the small signal parameters of the transistor Q_1.

i. $g_m = 0.53\ mho, r_\pi = 188\ \Omega$, and $r_o = 3.6\ k\Omega$
ii. $g_m = 0.32\ mho, r_\pi = 188\ \Omega$, and $r_o = 3.6\ k\Omega$
iii. $g_m = 0.53\ mho, r_\pi = 377\ \Omega$, and $r_o = 5.6\ k\Omega$
iv. $g_m = 5.3\ mho, r_\pi = 37.7\ \Omega$, and $r_o = 4.34\ M\Omega$

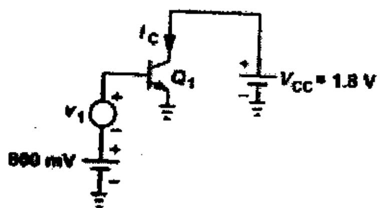


Fig. 3

(c) Among the 4 options given below, select the correct value of W/L of M_1 in Fig. 4 that places M_1 at the **edge-of-saturation** $\mu_nC_{ox} = 100\mu A/V^2$ and V_{TH} = 0.5V?

i. 4.8/0.18
ii. 4.0/0.18
iii. 7.48/0.18
iv. 5.48/0.18

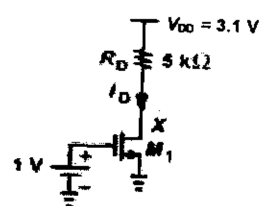


Fig. 4

3. Two identical MOSFETs are placed in series as shown in Fig. 5. If both devices operate as resistors, prove that the combination behaves as a single transistor, M_{eq}. Obtain the ratio of width and length of M_{eq} in terms of W/L. (Hint: Write expression of resistance of M_1 and M_2 as R_1 and R_2, respectively and then find the series resistance.) **[4 Marks]**

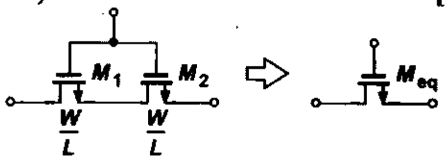


Fig. 5

4. A common emitter (CE) amplifier circuit is shown in Fig. 6. Given values of the circuit components are: R1 = 18.8 kΩ, R2 = 5.2 kΩ, C1 = C2 = 1 μF, C_L = 50 pF, Vcc = 12V, Forward current gain of the transistor, β = 200. **[5 x 4 = 20 Marks]**

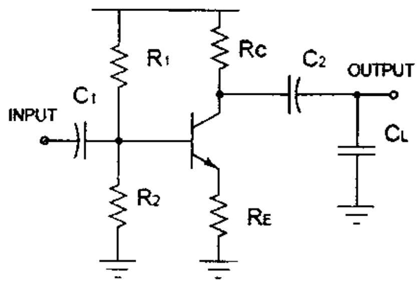


Fig. 6

(i) **Find the values** of R_E and R_C such that the operating point of the transistor is, I_{CQ} = 2.5mA and V_{CEQ} = 4.5V. Use these value of R_E and R_C for the subsequent parts of this question.
(ii) **Draw small signal equivalent circuit** of the amplifier. Using the small signal equivalent circuit, **derive the expression** of transconductance of the amplifier.
(iii) **Find the values** of voltage **gain** and the lower **cutoff frequency** of the amplifier.
(iv) For an input signal of $v_{in} = 1 + sin(2000\pi t - 180^\circ)$ volts, **neatly sketch** (including d.c. level and the phase) the voltage waveforms at the base, emitter and collector nodes of the transistor.
(v) How can we **increase the gain** of the amplifier? What is the **value of the gain** of the amplifier with your suggested modification?

5. Refer to the amplifier circuit shown in Fig. 7. Forward current gain of the two transistors in the circuit are, β_1 = 150 and β_2 = 49. Given values of the circuit components are: R1 = 15.5 kΩ, R2 = 560 Ω, C1 = 1 μF, C_L = 100 pF, Vcc = 12V. **[6 + 7 + 4 + 3 = 20 Marks]**

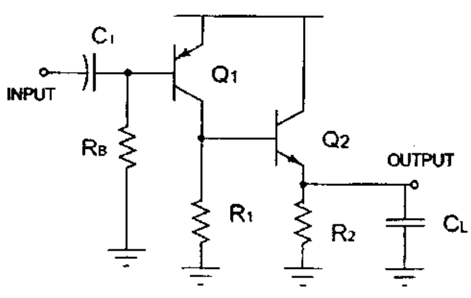


Fig. 7

(i) Find the **value** of R_B so that the d.c. voltage at the output node is 5.6V. With this value of R_B, find the **operating points** of the two transistors. Use this value of R_B for the subsequent parts of this question.

(ii) **Draw** the small signal equivalent circuit of the given amplifier. Using the small signal equivalent circuit, **derive the expression** of voltage **gain** and **output resistance** of the amplifier.
(iii) Find the **values** of the **upper cutoff frequency** and the voltage **gain** of the amplifier.
(iv) Find the value of maximum swing of the **output signal** (sinusoidal) with which both the transistors remain in active region of operation.

6. Construct the small-signal model of the circuit in Fig. 8 where M_1 and M_2 are in saturation. Obtain V_{out}/V_{in} and the output impedance, R_{out}. [Hint: For R_{out} apply test voltage V_x at the output and find the current, I_x, flowing through the test voltage V_x. $R_{out} = V_x/I_x$. V_{in} should be an AC ground during this analysis.] **[2+4+4 = 10 Marks]**

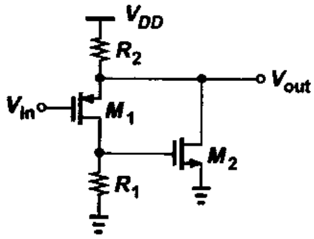


Fig. 8

7. Obtain the transfer function $\frac{v_{out}}{v_{in}}(s)$ for the circuit in Fig. 9. **[5+3+2 = 10 Marks]**
   (a) by exact analysis *i.e.*, by drawing the small signal model.
   (b) From the transfer function obtained in (a) identify the nodes and the corresponding poles.
   (c) Draw the corresponding Bode-plot for the transfer function obtained in (a). Annotate the poles as $\omega_{p1}, \omega_{p2}, \cdots, \omega_{pN}$ and zeroes as $\omega_{z1}, \omega_{z2}, \cdots, \omega_{zN}$. Since the resistor and capacitor values are not given you are free to appropriately assign the order of the poles. For example, you can choose the order as $\omega_{p1} < \omega_{p2} < \cdots < \omega_{pN}$ and $\omega_{z1} < \omega_{z2} < \cdots < \omega_{zN}$. The Bode plot should then be appropriately done.

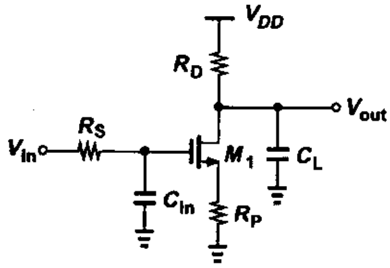


Fig. 9

8. Determine the voltage gain of the circuits given in Fig. 10 using the concept of G_m and R_{out}. Keep in mind that $R_{out}=R_{up}||R_{down}$. (Assume λ=0). **[9+9]**

(a) (b)

Fig. 10